Advance Journal of Food Science and Technology 11(1): 7-16, 2016
DOI:10.19026/ajfst.11.2347
ISSN: 2042-4868; e-ISSN: 2042-4876

Submitted: April 19, 2015 Accepted: May 10, 2015 Published: May 05, 2016

Research Article

Carbon and Nitrogen Pools in an Age-sequence of Olga Bay Larch (*Larix olgensis* Henry) Stands in North-Eastern China

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Abstract: To quantify the potential nitrogen and carbon sink and understand its implication to the regional carbon budget and future forest management, the N and C pools of Olga Bay Larch (*Larix olgensis Henry*) in five age groups (7.5 to 46 years old) were investigated in North-Eastern China. Twenty-seven sample trees have been cut down by ages and roots of twelve were dug up. Tree components (bark, stem, living and dead branches, foliage, root), shrub and herb, forest floor (coarse woody debris, fine woody debris, snag, slash piles and litter) and mineral soil were sampled. There was a significant difference between the N ($p = 0.000<0.05$) and C ($p = 0.000<0.05$) concentrations of the tree components, while the difference between the N ($p = 0.726>0.05$) and C ($P = 0.445>0.05$) concentrations of the stand ages is not significant. Total biomass were 24775.92, 66673.83, 91653.6, 112023.6 and 204103.2 kg/ha in young, middle, near-mature, mature and over-mature stand, respectively. The N and C pools of *Larix olgensis* ecosystem in each age group were 49.05, 56.50, 72.67, 68.73, 102.50 tN/ha and 89.97, 113.84, 133.58, 152.61, 210.26 tC/ha, respectively. Both N and C density in the mineral soil decreased with the increasing soil depth and the soil layer is an important part of total ecosystem N and C pools in each age group.

Keywords: Age-sequence, biomass, *Larix olgensis*, nitrogen and carbon pool

INTRODUCTION

Forest carbon-sink function plays a key role not only in the ecosystem of the mainland but also in the ecosystem of the world (Yang and Guan, 2008). The research on biomass is very important in the study of the growing and changing of the forest and in estimation of Carbon (C) and Nitrogen (N) pools in forest ecosystems (Regina and Tarazona, 2001; Zhang *et al*., 2010). The spacial distribution information on the biomass and C stocks is vital in explaining the ways and reasons of the spacial changing and analyzing the productivity and function of the forest (Mao *et al*., 2011).

N is the major element of protein and biological organism. According to the research of Cheng *et al*. (2012), the allometric growth constants of N storage gradually decrease with time in the process of forest regeneration and they infer it's the drop of the leaf biomass/total biomass ratio that cause the restrict of N absorption in ecological stoichiometry (Cheng *et al*., 2012). The response of C dynamics in ecosystem to the increase of the active cabin depends on the responses direction of input and output of the N deposition process (Tu *et al*., 2010).

The organic C and total N closely related (Li, 2008). The studies on C and N have an important implication in understanding the C budget and N cycle of the ecosystem (Arthur *et al*., 2001). Peichl and Arain (2007) suggested that age-dependent changes in allometery and biomass partitioning need to be considered in order to obtain appropriate biomass estimates at various development stages of forest ecosystems, which are required to improve regional and national estimates of forest biomass and C storage potentials (Peichl and Arain, 2007). Morford *et al*. (2011) suggested that forests associated with N-rich parent material contain on average 42% more C in above-ground tree biomass and 60% more C in the upper 30 cm of the soil than similar sites underlain by N-poor rocks.

Forest ecosystems include five C storage pools: Living trees, down dead woods, understory vegetation, forest floor and soil (Woodbury *et al*., 2007). Accurate estimates C of tree, forest floor and organic C in forest soils are important in determining their contribution to global C stocks (Sheikh *et al*., 2012).

Few studies have examined the effect of stand age on C and N storage in forest ecosystems, particularly in East Asia (Noh *et al*., 2010). *Larix olgensis*, one of the main edificators of taiga, distributes in the Great Khingan and Lesser Khingan Mountains area (Wang *et al*., 2000). Present study suggests that the C storage

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of *Larix olgensis* accounts for 12% China's the plant C storage (Cienciala *et al*., 2006).

To quantify the potential N and C sink and understand its implication to the regional carbon budget and future forest management, we estimated the changes of biomass *Larix olgensis* forests N and C storage in the northeast china. In this study, we quantified total tree layer biomass and N and C pools. In addition, we quantified forest floor biomass and N and C pools. Also we quantified soil organic N and C pools. Based on these data, we calculated total ecosystem N and C pools in *Larix olgensis* forests by ages in North-Eastern china.

MATERIALS AND METHODS

Site description: The study area is located in the Dongzhelinghe forest center, which is in the east of Langxiangtown, Yichun city, Heilongjiang province (128°55′30″~129°15′21″ E and 46°31′58″~46°49′38″ N). The study plantation area is 0.42×10^3 hm^2 and the volume is 3.62×10^4 m^3, young and middle age forest were in the majority in *Larix olgensis* plantation. The climate of the region is temperate continental monsoon climate, the annual precipitation average 618 mm and annual mean temperature is approximately 0.36°C. Table 1 shows the characteristics of study stands. The soil is a dark brown forest soil and its thickness is greater than 50 cm. *Larix olgensis* is as an important planting species is the dominant species there.

Measurements and data collection: Original data and samples were collected from July to August in 2009, 2010 and 2011, respectively. Measurements for every individual tree included Diameter at Breast Height (DBH), Height (H), first living branch height above ground, crown width, canopy density. Average DBH and H were calculated based on the collected data in order to select a mean tree for each stand.

We cut the tree stem into 1m sections and weighed each section (Wang 2006; Bollandsås *et al*., 2009). Positions, base diameter, length, status (i.e., live and dead) of branches in each section were recorded, respectively. Living branches, foliage and dead branches were weighted respectively. Root biomass sampling was performed concurrently with above-ground harvests. Within each stands, four 5 m^2 sub-plots were set up at four corners to investigate the shrub. Plant species, basal diameter, the crown with different direction (NS, WE), the average height, the height of living branch, number, growth condition and distribution of shrub were recorded. In each sub-plot, shape, length×width×height and real density of slash piles (SP) were recorded. Sixteen 1 m^2 micro-plots were set up in each shrub plot to investigate herb. Plant species, number, the average height, coverage, growth condition, distribution and biotemperature of herb were recorded. After finding the highest important value of shrub and herb, we could harvest and weight them to establish model estimate biomass. In each micro-plot, species, diameter (section of top and down), length and decay class of Coarse Woody Debris (CWD) and Fine Woody Debris (FED) were recorded. All samples were weighed, sub-sampled and took back to lab for moisture content determination and N and C concentration.

Soil profiles in each of plot were dug out; samples were collected at each layer of four depths (0-10, 10-20, 20-40, >40 cm); 100 cm^3 of soil was sampled at each layer of depths by stainless steel cans for bulk density determination (Lin, 2002; Li, 2008; Wang *et al*., 2011). Soil samples were air-dried at room temperature and analysed by the Soil Laboratory of the Department of Soil Sciences, BJFU, Beijing, China. Other soil samples were placed in plastic bags, transported to the laboratory and dried in an oven for 24 h at 105°C to quantify the soil gravimetric moisture content (Kim *et al*., 2010).

Table 1: Characteristics of study stands

Age group	Young	Middle	Near-mature	Mature	Over-mature
Altitude (m)	306	266~419	418~456	393~423	312
Slope direction	SW	SW	SW	SW	SW
Slope location	Lower	Lower	Lower	Lower	Lower
Slope (°)	9	0~6	6~13	6~8	9
Mean DBH[a] (cm)	4.3	9.1	14	17.6	27.4
Meantree height (m)	3.9	9.1	14.3	16.5	25.7
Density (tree ha^{-1})	1716	833~2475	1017~1550	883~1000	450
Tree coverage	0.3	0.8	0.8	0.7	0.7

a DBH, diameter at breast height of 1.3 m

Table 2: Regression of dry weight (g) in different components with the $(DBH)^2H$ for *Larix olgensis*

Tree component	N	β_0	β_1	R^2	F	S.E.	Sig.
Bark	27	0.012	0.8	0.981	1307.58	0.140	0.000
Stem	27	0.028	0.940	0.988	1740.260	0.122	0.000
Live branches	27	0.015	0.795	0.850	176.286	0.384	0.000
Dead branches	27	$2.14E^{-4}$	1.207	0.681	74.751	0.893	0.000
Foliage	27	0.057	0.503	0.602	51.483	0.157	0.000
Above biomass	27	0.080	0.852	0.978	1132.078	0.165	0.000
Root	12	0.024	0.801	0.969	281.57	0.287	0.000
Total biomass	12	0.101	0.824	0.986	548.89	0.191	0.000

Equations follow the form $y = \beta_0(x^{\beta 1})$; where x is $(DBH)^2H$; y is the dry weight of different components; S.E. is estimate of standard error

Biomass estimation: Usually allometric biomass regression equations are used to estimate the forest biomass (Arthur *et al*., 2001; Northup *et al*., 2005; Cienciala *et al*., 2006; O'Grady *et al*., 2006; Wang, 2006). Based on previous studies (Schmidt *et al*., 2009), we adopted the model $y = \beta_0(x^{\beta 1})$ as estimated forest biomass equations (Table 2), where x is $(DBH)^2H$, y is the dry weight of different components.

The biomass of shrub is estimated by the method of selecting and calculating the sample shrub according to regular proportion in each diameter class. The herbs with high frequency of occurrence, great number and high coverage are weighed by type, aboveground and underground part, respectively. The samples of shrub and herb are brought to the lab to dry to constant weight. In the end, the biomass can be estimated by the regression equations of biomass. This part was calculated by Liu (2011).

Biomass of debris comprises CWD, FED, SP, sang and litter. According to the relation of volume and biomass, we can calculate the biomass of debris with dry matter density of sample (Woodall *et al*., 2009; Ma *et al*., 2010; Domke *et al*., 2011).

Calculation of C and N soil storage is based on N and C concentration, the volume of coarse fragments, the thickness of layer and the soil bulk density (Vesterdal *et al*., 2008; Wang *et al*., 2011). For the heavy loam is dominant soil in study areas and fraction >2 mm is extremely rare, we calculate C and N soil storage according to the following equation:

$$C_s = \sum 0.1 H_i B_i C_i \quad (1)$$

$$N_s = \sum 0.1 H_i B_i N_i \quad (2)$$

where, C_s is soil organic C storage (tC/hm^2), N_s is soil total N storage (tN/hm^2), B_i is the soil bulk density (g/cm^3), H_i is the thickness of layer i (cm), C_i is the C concentration of layer i (g/kg), N_i is the N concentration of layer i (g/kg) and 0.1 is the unit factor.

C and N concentration of larix olgensis: Plant and soil samples were both analyzed for concentrations of total organic C and total N using the induction furnace method with a gas chromatographic elemental analyzer (Vario EL III, Elementar, Hanau, Germany) and the powdered samples size we used is no more than 0.3 mm for accurate estimates (Lamlom and Savidge, 2003). All values are shown as mean (SE).

ANALYSIS METHODS

N and C concentration variations among organs and age-classes were analyzed by Analysis of Variance (ANOVA). All statistical analyses are carried out using the Spass16.0 software and the accepted level of significance is $p<0.05$.

RESULTS AND DISCUSSION

These allometric equations provide a useful tool for rapid estimation of the biomass (Holly and Pearson, 2001). Table 3 shows the results of the biomass of vegetable layer (including tree, shrub and herb) estimated by biomass allometric growth equation. The tree layer biomass were 20064.94, 65040.83, 90836.25,

Table 3: Biomass distribution of Larix olgensis vegetable and floor layer by ages in North-Eastern China

	Biomass (kg/ha)				
	Young	Middle	Near-mature	Mature	Over-mature
Tree layer					
Stem	8658.38	31739.43	55335.24	69210.45	164580.30
Bark	2683.65	7039.67	7159.27	8018.34	16105.45
Live branches	2215.58	18041.77	3829.51	4822.23	4292.30
Dead branches	/	5164.73	3121.93	2613.64	137.16
Foliage	6507.33	1229.74	3767.21	4451.45	4577.44
root	975.99	1825.49	16140.17	20166.63	25643.37
Total	20064.94	65040.83	90836.25	106381.69	201243.61
Shrub layer					
Stem[1]	267.96	397.918	109.262	2880.645	1308.808
Foliage[1]	34.38	170.035	31.535	429.985	354.801
Root[1]	174.93	583.34	154.794	1614.687	1001.091
Total[1]	477.27	1151.29	295.59	4925.32	2664.70
Herb layer					
Above-ground[1]	1815.18	410.33	213.65	333.06	31.21
Below-ground[1]	2411.35	48.63	268.49	315.87	70.29
Total[1]	4226.53	458.96	482.14	648.93	101.50
sum	24768.74	66651.08	91613.98	111955.9	204009.8
Floor layer					
Snag	0.06	1.31	3.40	5.74	6.09
CWD	/	2.66	7.94	13.81	25.86
SP	0.46	3.32	9.84	22.96	31.85
FED	5.59	13.20	15.28	20.43	22.84
Litter	1.08	2.26	3.16	4.75	6.80
Total	7.18	22.75	39.62	67.69	93.45

[1]This part was calculated by Fengjiao Liu. CWD: Coarse Woody Debris; SP: Slash Piles; FED: Fine woody debris

Table 4: C and N concentration of *Larix olgensis* organs by ages in North-Eastern China

	Young		Middle		Near-mature	
	N (%)	C (%)	N (%)	C (%)	N (%)	C (%)
Foliage	1.92 (0.14)	47.8(0.09)	2.53(0.31)	48.97 (0.62)	2.7 (0.25)	49.37 (0.34)
Living Branches	0.57 (0.02)	48.29 (0.04)	0.55 (0.09)	48.84 (0.27)	0.6 (0.08)	47.19 (0.18)
Dead Branches	0.73 (0)	46.76 (0.04)	0.61 (0.03)	47.39 (0.47)	0.74 (0.11)	49.97 (1.13)
Stem	0.11 (0.01)	47.8 (1.56)	0.10 (0)	48.6 (0.19)	0.08 (0)	49.32 (0.3)
Bark	0.68 (0.01)	47.5 (0.04)	0.49 (0.07)	46.73 (0.37)	0.51 (0.03)	47.71 (0.22)
Root	0.58 (0.14)	44.32 (1.81)	0.5 (0.04)	46.92 (0.85)	0.55 (0.03)	46.22 (0.89)
Tree	0.70 (0.17)	46.81 (0.47)	0.94 (0.4)	48.04 (0.23)	0.93 (0.46)	48.25 (0.2)
	Mature		Over-mature			
	N (%)	C (%)	N (%)	C (%)		
Foliage	2.1 (0.11)	48.74 (0.2)	2.52 (0.1)	47.53 (0.26)		
Living Branches	0.6 (0.02)	47.3 (0.96)	0.55 (0.05)	48.61 (0.8)		
Dead Branches	0.53 (0.26)	48.33 (0.97)	0.44 (0.04)	47.24 (1.45)		
Stem	0.10 (0.01)	48.15 (0.69)	0.07 (0)	46.49 (0.28)		
Bark	0.46 (0.06)	46.71 (0.44)	0.48 (0.03)	47.67 (0.15)		
Root	0.37 (0.1)	44.98 (0.92)	0.35 (0.15)	45.24 (1.01)		
Tree	0.76 (0.35)	47.13 (0.54)	0.61 (0.25)	46.97 (0.39)		

Table 5: The weighted average C and N concentration of shrub, herb and floor layer of Larix olgensis forest in North-Eastern China

Shrub layer	N (%)	C (%)	Floor layer	N (%)	C (%)
Stem	0.57 (0.02)	48.93 (0.30)	Snag	0.41 (0.01)	45.07 (0.26)
Foliage	1.99 (0.01)	47.32 (0.08)	CWD	0.4 (0)	45.93 (0.01)
Root	0.32 (0.27)	44.75 (0.15)	SP	0.79 (0)	48.08 (0)
Herb layer			FED	1.45 (0)	36.13 (0.01)
Above-ground	1.70 (0.05)	42.12 (0.35)	Litter	1.12 (0.01)	47.15 (0)
Below-ground	1.33 (0.68)	40.2 (0.50)			

CWD: Coarse Woody Debris; SP: Slash Piles; FED: Fine woody debris

1006318.69, 201243.61 kg/ha and the shrub layer biomass were 477.27, 1151.29, 295.59, 4925.32, 2664.70 kg/ha and the herb layer biomass were 4226.53, 458.96, 482.14, 648.93, 101.50 kg/ha in young, middle, near-mature, mature and over-mature stands, respectively. And for the floor layer, the biomass (kg/ha) was 7.81, 22.75, 39.62, 67.69 and 93.45, respectively (Table 3).

Table 4 shows C and N concentration of Larix olgensis organs by age classes. By the analysis of variance, the N concentrations were significantly different among the tree components(single-factor ANOVA:$F_{5,192} = 563.201$,$P = 0.000<0.05$, within group Degrees of Freedom (DF) = 192, mean square variance (MS) = 0.038 and between group DF = 5, MS = 21.127), which is consistent with the result of Pinus densiflora in Korea by Noh *et al*. (2010). The N concentrations were not significantly by ages (single-factor ANOVA: $F_{4,193} = 0.513$, $p = 0.726>0.05$, within group degrees of freedom (DF) = 193, mean square variance (MS) = 0.597 and between group DF = 4, MS = 0.297). The C concentrations were significantly different among the tree components too(single-factor ANOVA: $F_{9,82} = 13.71$, $p = 0.0001<0.05$, within group Degrees of Freedom (DF) = 82, mean square variance (MS) = 4.497 and between group DF = 9, MS = 61.653).The C concentrations were not significantly by ages (single-factor ANOVA: $F_{10, 81} = 1.006$, $p = 0.445>0.05$, within group Degrees of Freedom (DF) = 81, mean square variance (MS) = 10.142 and between group DF = 10, MS = 10.208). Table 5 shows the weighted average C and N concentration of shrub, herb and floor layer of Larix olgensis forest in North-Eastern China.

The N and C pools of Vegetable layer: The C and N pools in the biomass of each stand were calculated by multiplying the mean concentration (Takahashi, 2005) of each component by its respective mass. Soil C and N pools were calculated from concentration and bulk density data (Liu *et al*., 2012).

The N pools (Mg/ha) of tree were 0.05, 0.37, 0.32, 0.32, 0.42 and C pools (Mg/ha) of tree were 7.10, 31.43, 43.39, 51.85, 100.12 for the young, middle, near-mature, mature and over-mature stands (Table 6), slightly lower than the previous study of Pinus densiflora by Noh *et al*. (2010), who suggested that N pools of Pinus densiflora was 0.09~0.59 tN/ha and that C pools was 9.3~104.9 tC/ha with the age increased. The N concentration in foliage was from 1.92% to 2.7%. The distribution of foliage N pools (Fig. 1a) was much higher than C pools (Fig. 1b), partly for the N concentration in foliage was much higher than that in other organs in each age groups (Table 4). Although the distribution of foliage N pools decreased in the first decade from 13.78 to 13.12%, the N pools increased with ages, which were 7.36, 31.11, 101.72, 93.48, 115.35 kg/ha for each age group stands (Table 6). The distribution of foliage accounted for 1.92% in middle stand and 4.29% in near-mature stand of total tree C

Table 6: C and N pools of Larix olgensis vegetable layer by ages in North-Eastern China

	Young		Middle		Near-mature		Mature		Over-mature	
	N	C	N	C	N	C	N	C	N	C
Tree layer	Mg/ha									
Foliage	0.01	0.18	0.03	0.60	0.10	1.86	0.09	2.17	0.12	2.18
Live	0.01	1.07	0.10	8.81	0.02	1.81	0.03	2.28	0.02	2.09
Dead	/	/	0.03	2.45	0.02	1.56	0.01	1.26	0.00	0.06
Stem	0.01	4.14	0.17	15.43	0.04	27.29	0.07	33.32	0.12	76.51
Bark	0.02	1.27	0.03	3.29	0.04	3.42	0.04	3.75	0.08	7.68
Root	0.01	0.43	0.01	0.86	0.09	7.46	0.07	9.07	0.09	11.60
Total	0.05	7.10	0.37	31.43	0.32	43.39	0.32	51.85	0.42	100.12
Shrub layer	kg/ha									
Stem	1.52	131.11	2.25	194.70	0.62	53.46	16.30	1409.50	7.41	640.40
Foliage	0.68	16.27	3.38	80.46	0.63	14.92	8.55	203.47	7.06	167.89
Root	0.57	78.28	1.89	261.04	0.50	69.27	5.22	722.57	3.24	447.99
Total	2.77	225.66	7.52	536.21	1.75	137.65	30.08	2335.54	17.70	1256.28
Herb layer	kg/ha									
Above-ground	30.90	764.56	6.99	172.83	3.64	89.99	5.67	140.28	0.53	13.15
Below-ground	32.01	969.36	0.65	19.55	3.56	107.93	4.19	126.98	0.93	28.26
Total	62.91	1733.92	7.63	192.38	7.20	197.92	9.86	267.26	1.46	41.40

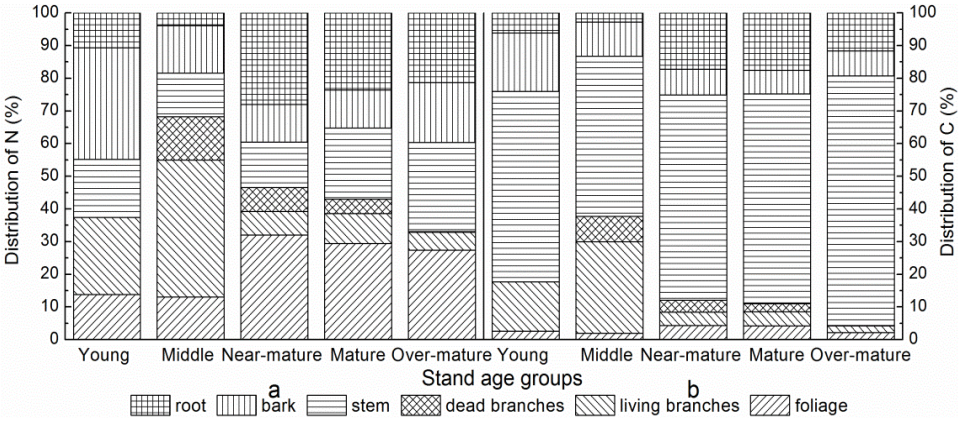

Fig. 1: Partition ratio variation of the N pools (a) and C pools (b) of tree layer of the Larix olgensis stands by ages

pools. The increased foliage C pools were, respectively 183.33, 602.20, 1859.87, 2169.64, 2175.66 kg/ha in different age groups.

There were no dead branches in young stands (Fig. 1a) and the N pools of dead branches were 31.50, 23.11, 13.85, 0.60 kg/ha, while C pools were 2447.56, 1560.03, 1263.17, 64.80 kg/ha for each age group stands, respectively (Table 6). The dead branches N and C pools decreased with stand ages. The N pools of living branches were 12.63, 99.23, 22.98, 28.93, 23.91 kg/ha and C pools were 1069.90, 8811.60, 1807.15, 2280.91, 2086.49 kg/ha for each age group stands, respectively (Table 6). With the stand becoming closing, the canopy biomass accumulated quickly and then both living and dead branches biomass increased, so that N and C pools increased, but they decreased sharply during forest near-mature for the competition among trees.

The N and C pools of stem increased with the age, the distribution of N pools was lower than the C pool (Fig. 1). The highest distribution of bark N pool was found in young stand (34.16%) and it ranged from 11.51 to 18.33% in other age groups. Our study suggested that the N pool of bark is important in total tree N pools, especially in young stand. The distribution of bark C pools ranged from 7.22% in mature stand to 17.96% in young stand. The aboveground forest biomass has significantly increased with forest regrowth on existent forests. Nearly 80% of total net sequestration was contained in the aboveground biomass C pool (Hu and Wang, 2008).

The N concentration in root was from 0.35 to 0.58% (Table 4), which is lower than root N concentration ranging from 0.56% (Turkish fir and Oriental spruce) to 0.74% (Austrian pine) among species by Akburak *et al*. (2013). The C concentration in root was from 44.32 to 46.92% (Table 5), that is similar to the means of root C concentration among the species by Akburak *et al*. (2013), and oak having the lowest (45%) and Scots pine having the highest (46%). Figure 1 shows root N pools were 5.66, 9.13, 88.77, 74.62, 89.75 kg/ha increased with age groups. Zhang *et al*. (2010) suggested that below-ground biomass does not appear to play a substantial role in the storage of N in this subtropical secondary forest at Laoshan Mountain. However, our results shows that the ratios of

roots N pools were 10.60, 3.85, 27.97, 23.54, 21.28% of total tree N pools in different age groups, respectively. That suggests below-ground plays a key role in the storage of N in Northeast China. The root C pools were 432.56, 856.52, 7459.99, 9070.95, 11601.059 kg/ha in different age groups. The distribution of root C pools decreased from 6.09 to 2.7% in forest initial stage and reached 17.20% when forests get mature. That is lower than the proportion of belowground biomass C pool (coarse and fine roots) in the total biomass C pool maintained at 21-22% in Carolina Piedmont by Hu and Wang (2008).

Understory plants N storage of each age group stands were 62.91, 7.63, 7.2, 9.86, 1.46 kg/ha and the C storage is 1733.92, 192.38, 197.92, 267.26, 41.4 kg/ha, respectively. Figure 2 shows that the process of understory plants C (Fig. 2a) and N (Fig. 2b) storage decrease sharply at first and then the fluctuation become moderate. Due to the herbs in initial stage of stand development when stand do not reach close, the herb can obtain so much illumination that grow well and accumulate mass biomass. Correspondingly, the storage of C and N reach maximum. With the stand becoming closing, tree layer grow fast before maturity and herb layer deteriorate gradually due to insufficient illumination, so that the biomass and the storage of N and C of herb layer decrease sharply. But in mature forest the competition of tree layer become intense, then some trees become fallen dead wood and finally

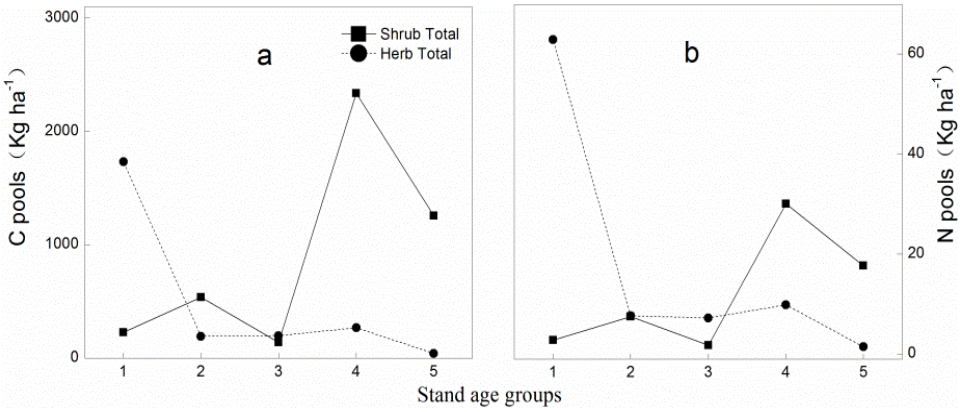

Fig. 2: Partition ratio variation of the C pools (a) and N pools (b) of shrub-herb layers of the *Larix olgensis* stands by ages. 1, 2, 3, 4, 5 stand for young, middle, near-mature, mature, over-mature stand respectively

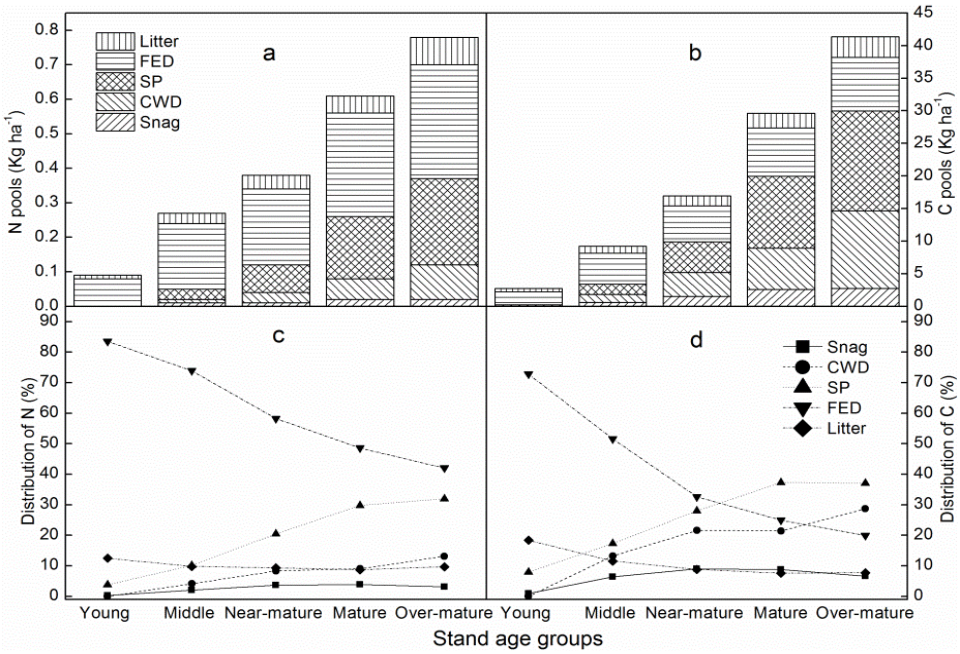

Fig. 3: CWD: Coarse woody debris; SP: Slash piles; FED: Fine woody debris; N pools (a) and C pools (b) in the forest floor layers of the *Larix olgensis* stands; Partition ratio variation of the N pools (c) and C pools (d) of each organs in forest floor layers of the *Larix olgensis* stands by ages

the illumination condition of understory improves. As a result, parts of herbs obtain a little rehabilitation and the biomass of herb layer rise again in a small range. When the stands reach mature period completely, the illumination condition of understory improves a lot, with the mature trees dying gradually and the tending measures like cutting down some certain tree. Oppositely, because dominant tree and shrub species with high competition ability invade, the illumination for herb layer is weakened gradually, which lead to herb layer declining gradually so that the accumulation of mass biomass decrease and so does the storage of C and N.

The N and C pools of forest floor layer: In our study, N and C concentrations in forest floor ranged from 0.4~1.45% and 36.13~48.08%, respectively (Table 6). Figure 3 shows that the forest floor N (Fig. 3a) and C (Fig. 3b) pools increased with stand ages, partly due to the fact that the biomass increased by the large trees in old-growth stands are more susceptible to wind damage than small trees in young stands (Taylor *et al*., 2007; Noh *et al*., 2010). The distribution of FED N and C pools of total forest floor decreased from 83.5, 72.9 to 42.1, 19.9%, with the stand ages, respectively (Fig. 3c). However, the ratio of FED pools is highest among the forest floor components. The distribution of N pools of SP, CWD and snag in total forest floor were increased from 3.7, 0, 0.23 to 31.9, 13, 2.1%, respectively (Fig. 3c) and the distribution of C pools were increased from 8.0, 0 to 37.3, 28.7%, respectively (Fig. 3d). Noh *et al*. (2010) suggested that the CWD and forest floor did not show any significant changes or temporal trends of Pinus densiflora stand. The C pools increased with stand ages and reached highest (9.1%) in near-mature stand, then decreased to 6.6% in over-mature stand. The ratio of litter N and C pools decreased first 20 years and then to be stable.

The N and C pools of minerals soil layer: N and C in the minerals soil were 48.93 and 80.91, 56.11 and 81.66, 72.34 and 89.82, 68.37 and 98.09, 102.06 and 108.76 t/ha for each age groups, respectively. However, the results were much higher than the reported for Pinus densiflora with an age-sequence by NOH Nam-Jin the maximum of 84.7 tC/ha and 7.6 tN/ha in the 71 year old stand (Noh *et al*., 2010). Both N and C density in the mineral soil decreased with increasing soil depth, this was same as previous studies (Jobbágy and Jackson, 2000; Taylor *et al*., 2007; Li, 2008; Xi *et al*., 2009; Lange, 2011). The N (Fig. 4a) and C (Fig. 4b) density of soil increased with stand age in 1-10 cm soil depth, it was ranged from 28.69 to 60.12 tN/hm^2 and 36.29 to 55.35 tC/hm^2, respectively. The highest soil total N concentration was found in surface soil (0-10 cm), there were 12.75, 13.75, 17.85, 21.80, 25.38 g/kg and the lowest were 2.60, 3.69, 8.69, 2.24, 9.61 g/kg below

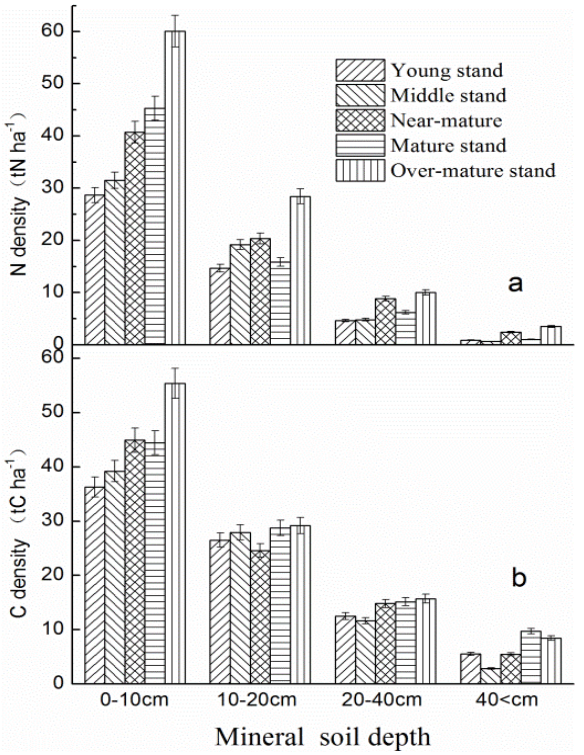

Fig. 4: N (a) and C (b) density in the mineral soil layers of the *Larix olgensis* stands; The horizontal bars indicate one standard error from the mean

40cm, by stands age, respectively. It was little higher than that in northeast by Wang *et al*. (2012) (0.03~18.7 g/kg) and significantly higher than Cunninghamia lanceolata soil total N concentration (1.58~3.87 g/kg) (Cai and Huang, 2006; He *et al*., 2006) and broadleaved soil total N concentration (2.21 g/kg) (Smithwick *et al*., 2009).

The N and C pools of ecosystem: Ecosystem C storage of young, middle, premature, mature and over-mature stage were 89.97, 113.84, 133.58, 152.61, 210.26 tC/ha, respectively, NOH Nam-Jin suggested that total ecosystem C storage showed a similar sigmoidal pattern to that of tree C storage as a function of the age-sequence (Noh *et al*., 2010), which is similar to our study on total ecosystem C pools (Fig. 5a and b). Ecosystem N pools of young, middle, premature, mature and over-mature stage were 49.05, 56.50, 72.67, 68.73, 102.50 tN/ha, respectively (Fig. 5a). The distribution of vegetable layer in total ecosystem C pool increased from 10% in young stand to 48.2% in over-mature stand, while soil layer decreased from 89.9 to 51.7%. The soil layer is an important part of total ecosystem N pools. Soil N, which is the highest in young stand, is higher than 99% in each age group. This is similarly as the previous study that Mexican tropical dry forest soil C comprised 37-90% of the total ecosystem C, whereas soil N comprised 85-98% of the total by Jaramillo and Kauffman (2003). In addition, our study shows that the forest floor C pools played an

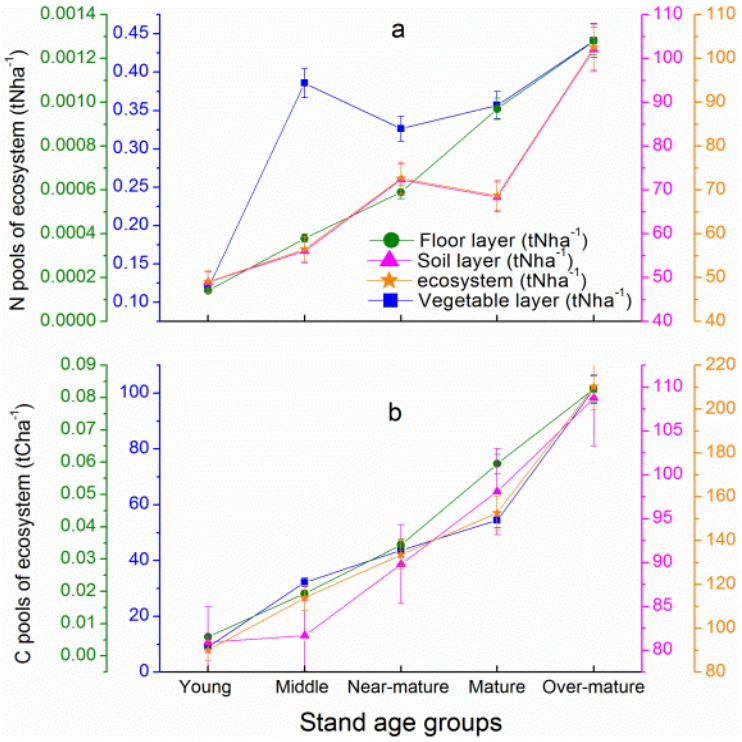

Fig. 5: N (a) and C (b) Pools of the Larix olgensis ecosystem; the horizontal bars indicate one standard error from the mean

insignificant role in total ecosystem C storage and the ratio of forest floor N pools is smallest in total ecosystem N storage. The highest ratio of forest floor N pools was in over-mature stand and lowest was in young stand. The highest ratio of forest floor C pools was 0.08 tC/ha in over-mature stand (3.9%). For the nutrient content is higher in dark soil in northeast china, the N concentration is higher the other areas. Partly due to the fact that the annual mean temperature and the annual mean precipitation are low in our study areas, the rate of decomposition of litter fall was low and the soil nutrition loss less.

ACKNOWLEDGMENT

The research was supported by the project of forestry science and technology research (No.2012-07). I am grateful for the assistance of Wei Ma, Feng-Jiao Liu, Xiao-Dan Yi, Xiao-Yu Guo and Yun-Fei Dong with the tree harvesting and sample processing. I also thank the two anonymous reviewers for their valuable comments.

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